Sensing and Navigation System for a Multiple-AUV Testbed

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LONG-TERM GOALS

The long-term goal is to enable the creation of a multiple-AUV testbed in which control strategies for network coordination can be studied in three-dimensional space.

OBJECTIVES

The objective of this project is to provide a sensing and navigation system that will support the coordination of multiple underwater vehicles in a freshwater, laboratory test tank. At Princeton University, an investigation into coordinating control strategies is already underway and an indoor multiple AUV experimental testbed is under development. The indoor, freshwater experiment will allow for comprehensive testing of control architectures, low-level control laws and dynamics of a fleet of AUVs in an environment that can be controlled and manipulated as desired. A key challenge to operating a group of AUVs in an indoor tank or pool is the development of a sensing and navigation system that provides to each vehicle not only its own position and attitude but also the relative position and attitude of at least its nearest neighbors. The aim of sensing and navigation system is to provide for this critical capability for a group of AUVs.

APPROACH

In order to create a testbed for experimenting with network control laws, it is necessary that each AUV not only navigate individually but also sense the relative position and attitude of its nearest neighbors. Furthermore, this is to be done in a tank environment, i.e., there will be walls to contend with. The sensing and navigation instrumentation is intended to address these needs using acoustic and optical solutions. To sense the absolute position of each vehicle we consider using acoustics at appropriate frequencies to minimize the influence of the walls. Three baseline stations will send out signals and each of the AUVs in the network will receive these signals and compute on-board their own position in the tank. Attitude will be measured using a fiber optic gyro and a magnetic compass (the gyro is needed to complement the compass because of possible problems with magnetics introduced by metal around the tank). Relative position and attitude measurements will be determined two ways, and the two will be fused to get the best kind of information for feedback control. The first method will be to use radio-frequency (RF) communication via a central computer so that each vehicle can be given the absolute positions of its nearest neighbors. Each vehicle can then calculate the relative positions of its neighbors by subtracting its own position from its neighbors. The second method will use optics to determine directly the relative position and attitude of a vehicle's nearest neighbors. This includes the

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use of position sensitive devices (PSDs) and stereo computer vision. The PSDs will also be used for some simple communication directly between vehicles (e.g., by means of sensing and then decoding light pulses). The stereo vision system will also be used for sensing objects in the environment, for example, in the context of a search task or an obstacle avoidance task.

WORK COMPLETED

As part of the larger testbed development, we have designed and constructed a prototype “grouper” vehicle. Thrusters have been designed (matching propeller characteristics with motor characteristics) for this prototype. Further we have designed an interface for smart sensors and actuators. We have implemented the interface design on the thrusters, a depth sensor and a magnetic compass. In particular, we have operated the vehicle under closed-loop depth control.

Further, towards the sensing and navigation system, we have performed testing of an RF-modem for underwater communication in the test tank. We have acquired a fiber optic gyro for heading reference. We have made significant progress on the development of a vision-based heading module using position sensitive devices (PSDs). Two student projects contributed to this effort. The PSD work is in progress as we aim to use the technology for relative position/heading measurements of neighboring vehicles. An acoustic navigation system appropriate for the tank environment has been ordered as has an acoustic doppler velocity meter. Both are expected to be delivered in November 2001.

RESULTS

First results in closed-loop control of the grouper prototype show promise for the testbed design as a development and testing platform. Early progress on sensing and navigation using PSDs shows promise for their use in heading and position measurement both with respect to a fixed reference as well as a moving reference (neighboring vehicle).

IMPACT/APPLICATIONS

The sensing and navigation system will make it possible to create a multiple-AUV testbed in which control strategies for group coordination can be studied in three-dimensional space. Existing testbeds for group coordination are typically confined to two dimensions; for example, robotics researchers use mobile robots on the ground to investigate coordinating controllers. Furthermore, fluid dynamic effects between vehicles can be examined in the multiple-AUV testbed. While coordinating strategies for multiple vehicles should be tested at sea, a laboratory testbed makes it possible to develop and test these strategies beforehand (and afterwards) in a readily accessible environment that can be controlled and manipulated as desired. That is, the multiple-AUV testbed can be used as a proving ground to prepare for the at-sea trials. In our other underwater vehicle research projects, e.g., the underwater gliding project, we have found such laboratory testbeds invaluable both for research and education.

Research in coordination of a fleet of AUVs has the potential for significant impact since it is expected to be useful for effective and efficient adaptive ocean sampling that would not otherwise be possible with individual vehicles.

TRANSITIONS

This work has just begun so no transitions have been made.

RELATED PROJECTS

This DURIP project is closely related to my ONR project on Dynamics and Control of Underwater Gliding. The advantages associated with underwater gliders are expected to be greatest when multiple gliders are operated cooperatively in a network.

I participate in an NSF/KDI funded project joint with A.S. Morse (Yale), P. Belhumeur (Yale), R. Brockett (Harvard), D. Grunbaum (U. Washington) and J. Parrish (U. Washington) on coordination of natural and man-made groups. We are studying schooling of fish and "schooling" of autonomous underwater vehicles. Development of the Princeton multi-vehicle testbed was initiated as part of this project.

I have a new AFOSR funded project on Coordinated Control of Groups of Vehicles. This is a joint project with Vijay Kumar and James Ostrowski at University of Pennsylvania. A focus of the project is understanding cooperation in the context of coordinated control of distributed, autonomous agents, and the collection and fusion of the sensor information that they retrieve. The testbed would be ideal for testing in this context.

With my colleague Edward Belbruno, I have worked on a project for Global Aerospace Corporation (funded by NASA) on low-energy trajectory control of a stratospheric balloon network. The objective is to manage the geometry of the constellation of balloons for science and communication applications in the presence of a non-uniform flow field at 35 km altitude. The balloons can be controlled in a limited way with sails. This project is related to the problem of coordination of groups of underwater vehicles in a non-uniform flow field.

PUBLICATIONS

R. Bachmayer and N.E. Leonard, "Experimental Test-bed for Multi-Vehicle Control, Navigation and Communication", *Proceedings 12th International Symposium on Unmanned Untethered Submersible Technology*, Durham NH, 2001.

N.E. Leonard and E. Fiorelli, "Virtual Leaders, Artificial Potentials and Coordinated Control of Groups", *Proceedings of the 40th IEEE Conference on Decision and Control*, 2001, in press.

T.R. Smith, H. Hanssmann and N.E. Leonard, "Orientation Control of Multiple Underwater Vehicles with Symmetry-Breaking Potentials," *Proceedings of the 40th IEEE Conference on Decision and Control*, 2001, in press.